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MODELING OF AN INDUCTIVE ADDER KICKER PULSER FOR A PROTON RADIOGRAPHY SYSTEM*

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Abstract

An all solid-state kicker pulser for a proton radiography system has been designed. Multiple solid-state modulators stacked in an inductive-adder configuration are utilized in this kicker pulser design. Each modulator is comprised of multiple metal-oxide-semiconductor field-effect transistors (MOSFETs) which quickly switch the energy storage capacitors across a magnetic induction core. Metglas is used as the core material to minimize loss. Voltage from each modulator is inductively added by a voltage summing stalk. A circuit model of a prototype inductive adder kicker pulser modulator has been developed to predict the performance of the pulser modulator. The modeling results are compared with experimental data.

I.INTRODUCTION

A proton radiography system can provide time-resolved, 3-D radiography capabilities for a hydrodynamic event. For a proton machine with acceleration by synchrotrons, a flexible extraction system which is capable of extracting individual proton bunches in the ring at arbitrary times is needed. This requires a kicker modulator with fast switches that can open under load. The closest technology to meet this requirement is the modulator design approach developed at LLNL for Dual-Axis Radiographic Hydrodynamic Test facility (DARHT-II) [1]. The original design of the pulser was based on planar triodes [2]. Although the performance of the pulser based on this design was very good, the availability of the high frequency planar triodes in the future has become a concern. This led to the development of an all solid-state kicker pulser design for DARHT-II (Figure 1). The new pulser design was based on the Advanced Radiograph Machine (ARM) modulator technology [3]. It uses multiple solid-state modulators stacked in an inductive-adder configuration. This modular design approach facilitates scale-up to meet the needs of the proton radiography system.

Prototype kicker pulser modulator boards for the proton

Figure 1. DARHT-II inductive adder kicker pulser.

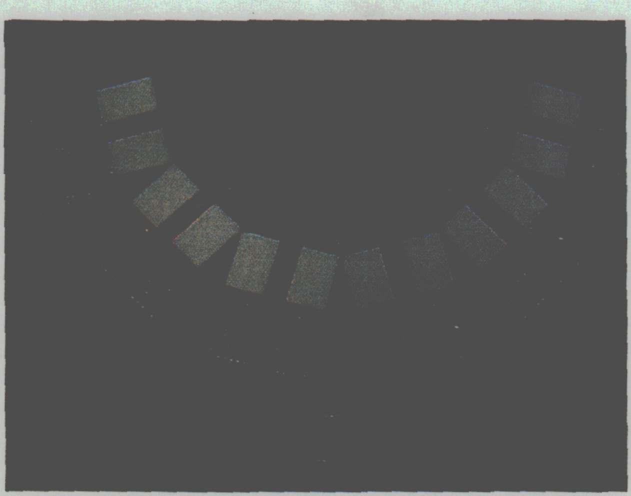

Figure 2. A prototype kicker pulser modulator board.

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radiography system have been fabricated and tested (Figure 2). Each modulator is comprised of multiple power metal-oxide-semiconductor field-effect transistors (MOSFETs) which were selected as the switching device. They can quickly switch the energy storage capacitors across a magnetic induction core. Metglas is used as the core material to minimize loss. Voltage from each modulator is inductively added by a voltage summing stalk. The cross section of this solid-state kicker pulser is shown in Figure 3. For the purpose of illustration, only three stacked modules are shown in the figure. On each stack, there are two modulator boards with twelve MOSFETs on each board. The secondary winding is a metal rod which is placed on the centerline of the kicker pulser. The rod can be grounded at either end to generate a positive or a negative output voltage.

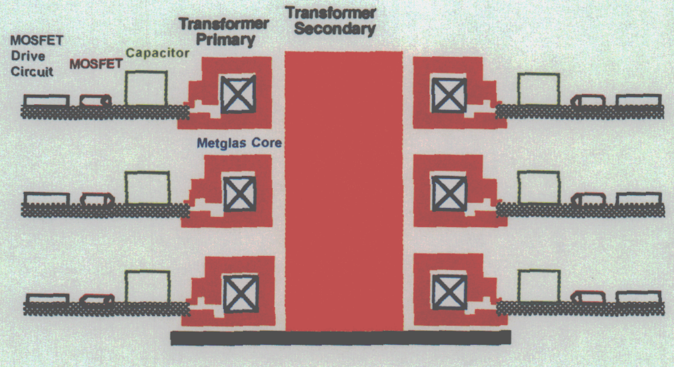

Figure 3. Cross section of the solid-state kicker pulser.

II.CIRCUIT MODEL OF A PROTOTYPE KICKER PULSER MODULATOR

A lumped element circuit model of the inductive adder kicker pulser modulator has been developed to simulate the output voltage waveform. Figure 4 shows the circuit model of a prototype kicker pulser modulator board. In the figure, X1, X2, X3, X4, X5, and X6 are sub-circuits. K1 is a transformer with 1:1 turns ratio. A circuit diagram of the sub-circuits is shown in Figure 5. Each sub-circuit is comprised of two MOSFETs M1 and M2, and two energy storage capacitors C1 and C2. MOSFETs are modeled based on the data sheet provided by the manufacturer. The resistance and inductance associated with each capacitor are included in the circuit model. They are about 0.005 Ohms and 15nH, respectively. The 0.22uF capacitor and the diode D1 connected in series provide protection for the MOSFETs against overvoltage transient which can be generated by the energy stored in the primary of the transformer and the stray loop inductance. The 0.22uF capacitor is initially charged to the same voltage as the energy storage capacitors. When the MOSFET is turned on, the diode D1 is off. Therefore, the 0.22uF capacitor is prevented from discharging through the MOSFET. When the MOSFET is turned off, the transient voltage which may exceed the 0.22uF capacitor voltage turns the diode on such that the capacitor can absorb the energy. The resistor parallel to the diode allows the excess capacitor voltage to discharge into the energy storage capacitor between bursts.

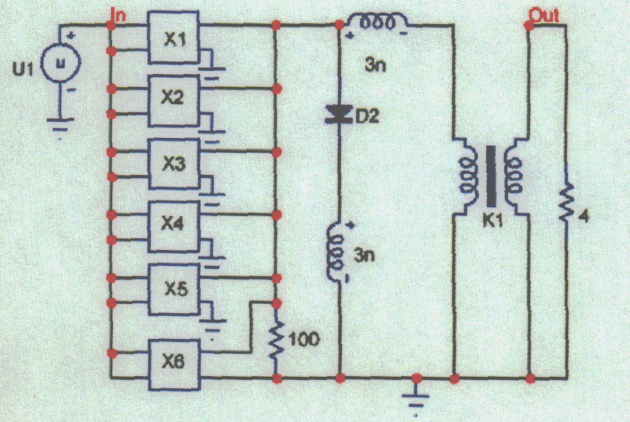

Figure 4. Circuit model of a prototype kicker pulser modulator board.

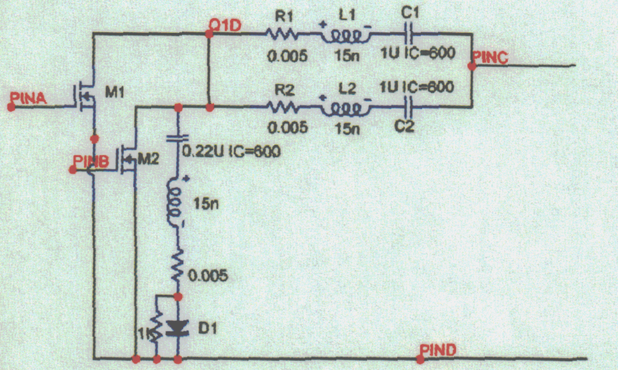

Figure 5. Circuit diagram of X1, X2, X3, X4, X5, X6 sub-circuits shown in Figure 4.

III.SIMULATION RESULTS

Output voltage waveforms are simulated using the circuit model for different pulse widths. Input waveforms at the gate terminal of a MOSFET are obtained from the experimental measurements. The digitized voltage waveform is then used in the input wave generator U1 in the circuit during simulation. Figure 6 shows the 75ns input pulse at the gate terminal of a MOSFET.

For the case of 75ns input pulse, the capacitors are charged to 600V initially. The simulated voltage waveform at the drain terminal of a MOSFET is displayed in Figure 7.

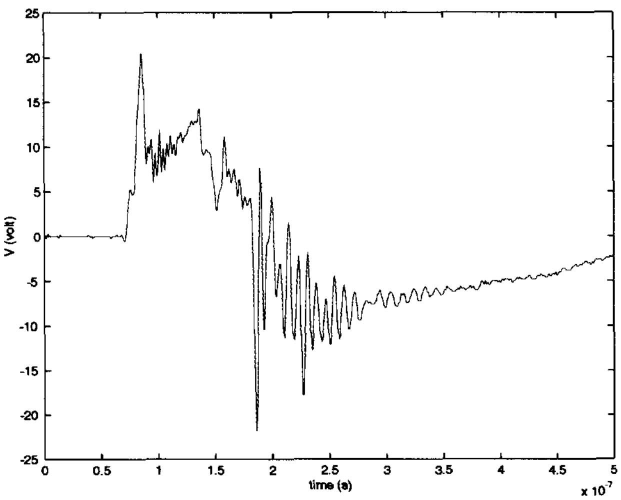

Figure 6. 75ns input pulse at the gate terminal of a MOSFET.

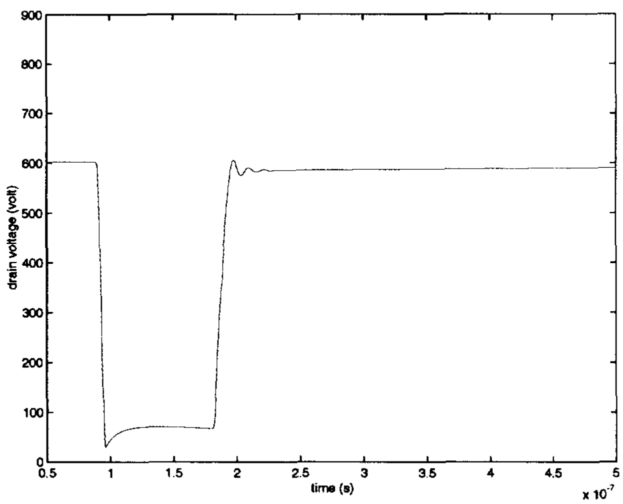

Figure 7. Voltage waveform at the drain terminal of a MOSFET for 75ns input pulse.

Figure 8 shows the output voltage waveform at the load. The dashed curve represents the simulated load voltage. The waveform is very similar to the drain voltage waveform except that they differ by 600 volts. The load voltage waveform from the experimental measurements is displayed as a solid curve in Figure 8. The figure shows that the simulation results are in good agreement with the measurements except that there are overshoots at the end of the measured voltage waveform. The overshoots are caused by the magnetization current in the magnetic core. The cores require reset so that they do not saturate during a voltage pulse. The use of a reset circuit will reduce the voltage overshoot.

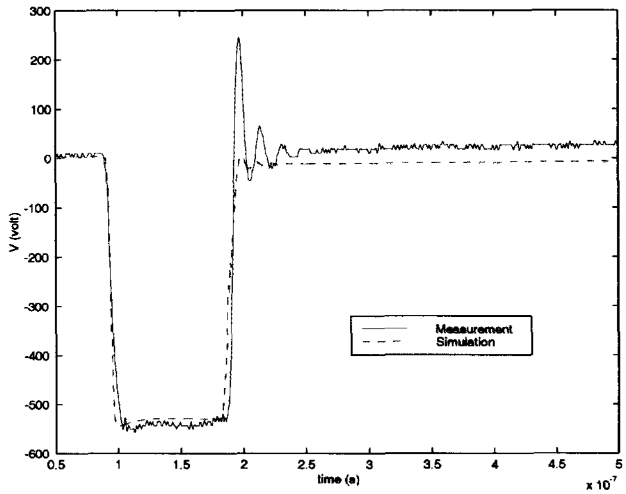

Figure 8. Comparison of simulation with measurements of the output voltage for 75ns input pulse.

The circuit model is also used to simulate the output voltage for the case of 120ns input pulse. Figure 9 shows the 120ns input pulse at the gate terminal of a MOSFET. For the case of 120ns input pulse, the capacitors are charged to 500V initially. Figure 10 displays the waveform at the drain terminal of a MOSFET.

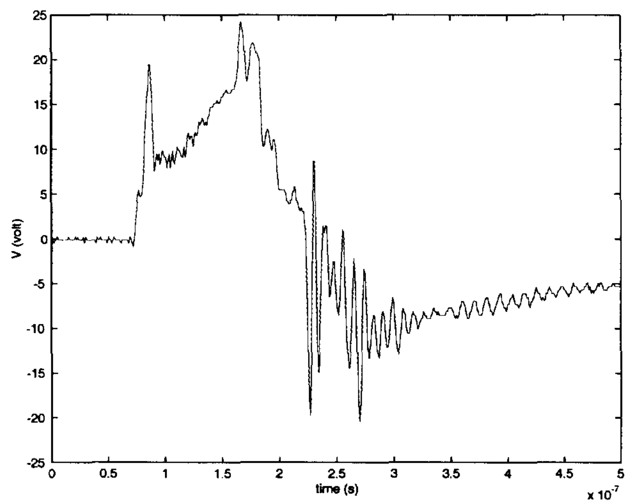

Figure 9. 120ns input pulse at the gate terminal of a MOSFET.

Figure 11 shows the output voltage waveform at the load. Again, the dashed curve represents the simulated load voltage. The waveform is very similar to the drain voltage waveform except that they differ by 500 volts. The load voltage waveform from the experimental measurements is displayed as a solid curve in Figure 11. Like the case for 75ns input pulse, the simulation results are in good agreement with the measurements except for the overshoots at the end of the measured voltage waveform caused by the magnetization current in the magnetic core .

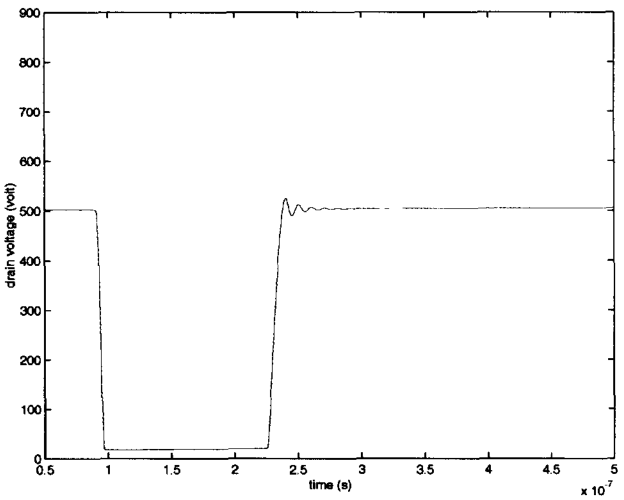

Figure 10. Voltage waveform at the drain terminal of a MOSFET for 120ns input pulse.

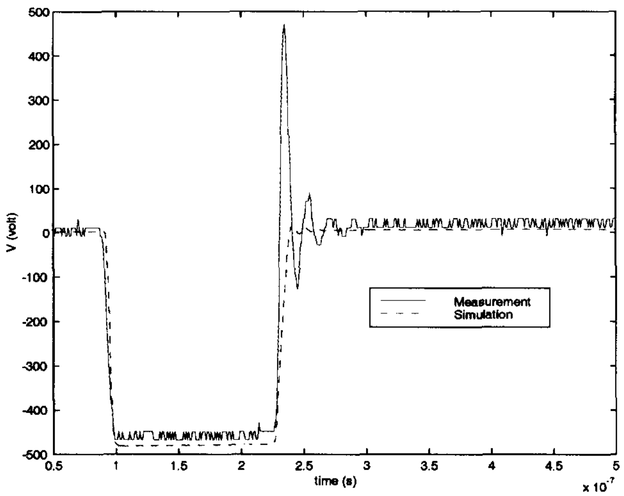

Figure 11. Comparison of simulation with measurements of the output voltage for 120ns input pulse.

IV.SUMMARY

A circuit model of a prototype inductive adder kicker pulser modulator for a proton radiography system has been developed. Output voltage waveforms were simulated using the circuit model for different input pulse width. The simulation results are in good agreement with the measurements except for overshoots at the end of the measured voltage waveform. The overshoots are caused by the magnetization current in the magnetic core. The use of a reset circuit will reduce the voltage overshoot.

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